Optical-Bias-Controlled and Temperature-Stabilized Electric Field Sensor Using Mach-Zehnder Interferometer

著者	Kobayashi Ryuichi, Kuwabara Nobuo
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OPTICAL-BIAS-CONTROLLED AND TEMPERATURE-STABILIZED ELECTRIC FIELD SENSOR USING MACH-ZEHNDER INTERFEROMETER

Ryuichi KOBAYASHI and Nobuo KUWABARA

NTT Telecommunication Networks Laboratories
3-9-11 Midori-Cho Musashino-Shi, Tokyo Japan 180

Abstract

This paper describes an electric field sensor which can control optical bias angle and improve the temperature drift of the sensitivity. The optical bias angle is controlled by applying a suitable stress to the $LiNbO_3$ substrate, and the temperature drift is reduced by inserting a Si semiconductor layer between the electrode and the SiO_2 buffer layer. The optical bias angle can be changed from 40[$deg.$] to 90[$deg.$], and temperature drift of the insertoin loss is within 2[dB] over a temperature range from 0[$deg.$] to 40[$deg.$].

Introduction

Recent progress in EMC measurement has created a need for a new electric field sensor which is small enough to measure the electric field close to the measurement equipment and is wideband enogh to measure the electromagnetic impulses. Many electric field sensors using optical technology have been developed to measure the electric field accurately because an optical fiber does not influence the electric field distributions. An electric field sensor using an optical modulator is useful for EMC measurement because it can operate over a wide frequency range without needing a battery. A sensor using a bulk crystal optical modulator[1] and one using a Mach-Zehnder interferometer[2] have been developed. At an electric field sensor using Mach-Zehnder interferometer, the minimum detectable electric field strength is about 1[mV/m] and the frequency range is from 100[Hz] to 1[GHz]. However, the temperature drift needs to be improved and an method of optical bias angle control has not been clarified.

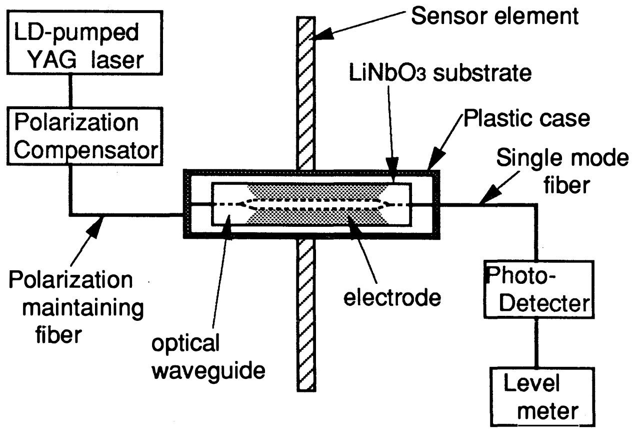

Fig. 1 Configuration of the conventional electric field sensor using Mach-Zehnder interferometer

This paper describes an optical-bias-controlled and temperature-stabilized electric field sensor using a Mach-Zehnder interferometer.

Configuration

Conventional sensor

Figure 1 shows that the configuration of the conventional electric field sensor using Mach-Zehnder interferometer, which is formed by Ti diffusion on a 40[mm] × 10[mm] × 0.5[mm] $LiNbO_3$ substrate. The sensor consists of an optical source, a pair of optical fibers, an optical modulator, sensor elements, and a photo-detector. When an electric field is applied to the sensor elements, a voltage is induced across the gap of the optical modulator. The incident optical power at the optical modulator is modulated by this voltage. The applied electric field strength is obtained by measuring the modulated optical signal level.

This sensor has two advantages:It minimizes the disturbance to the electric field because it is constructed from nonmetallic materials except for the sensor elements, therefore, it can obtain the electric field strength precisely. It can operate over a wide frequency range because a Mach-Zehnder interferometer operates from DC to $4[GHz]$[3].

When a voltage V_m is applied to the interferometer, the output optical power is given by

$$I_{out} = \frac{I_{in}}{2}\left\{1 + \cos\left(\pi\frac{V_m}{V_\pi} + \varphi\right)\right\} \quad (1)$$

where I_{in} and I_{out} are input and output optical powers at the interferometer, V_π is the half wave voltage, and φ is the optical bias angle. The optical bias angle is the phase difference between the optical waves propagating into the two arms of the interferometer. This angle should be tuned to obtain the best sensitivity and linearity.

Figure 2 shows a relationship between the optical power and the electrode voltage. Under ordinary conditions, the relationship is represented by the dotted line in Fig. 2. The optical bias angle is about $0[deg.]$ because the phase difference between the arms is almost $0[deg.]$ and the arms are the almost same length. To obtain the best sensitivity and linearity, the relationship should be shifted the dotted line to the solid line in Fig. 2. This condition corresponds to an optical bias angle of $90[deg.]$, which is obtained by equation (1). When the optical bias angle is tuned to $90[deg.]$ and $V_\pi \gg V_m$, equation (1) becomes

$$I_{out} = \frac{I_{in}}{2}\left\{1 + \frac{\pi}{V_\pi}V_m\right\} \quad (2)$$

However, a method of tuning the optical bias angle has not clarified and temperature stability should be improved.

New electric field sensor

A configuration of new electric field sensor using Mach-Zehnder interferometer is illustrated in Fig. 3. The new sensor uses Mach-Zehnder interferometer which is formed by Ti diffusion on a $55[mm] \times 1[mm] \times 0.5[mm]$ $LiNbO_3$ substrate. The new sensor consists of Mach-Zehnder interferometer with Si-coated, sensor elements, a fixture and a screw.

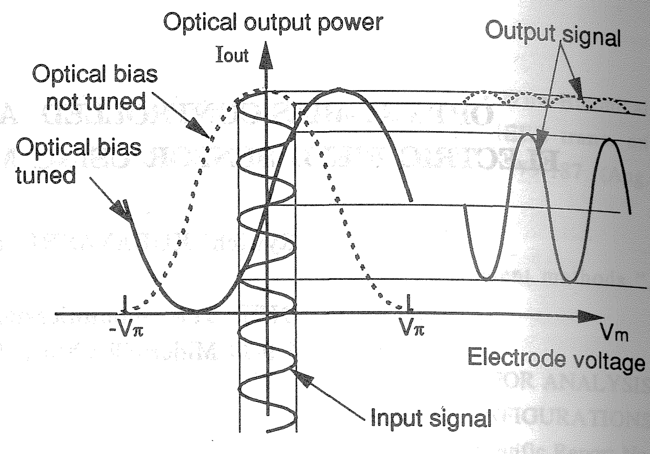

Fig. 2 Optical output power vesus the electrode voltage.

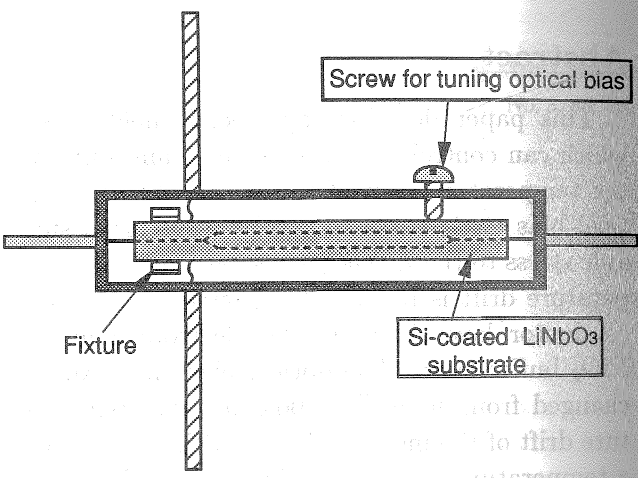

Fig. 3 Features of the new electric field sensor

The optical bias angle is usually tuned by applying a DC voltage between the two electrodes. However it is difficult to apply the DC voltage with this sensor because if DC voltage apply to this sensor, it must contain a power supply.

Instead, a stress is applied to the $LiNbO_3$ substrate in order to change the electro-optical constant by the photoelastic effect. The stress is applied using the screw in Fig. 3. This creates a phase difference between the two arms, so the optical bias angle can be tuned.

The sensitivity of the sensor drifts due to variations in temperature. The temperature drift of the interferometer has been studied and mechanisms have been explained[4]. The mechanisms and solution to this problem are illustrated in Fig. 4. The optical modulator consists of a $LiNbO_3$ substrate, SiO_2 layer, and electrode as shown Fig.4 (a). When the temperature changes, electric charges appear on the surface of the substrate due to the pyroelectricity. These electric charges accumulate on the electrode by electrostatic induction. As a result, an electric field appears in the optical waveguide due to the charge discontinuity on the upper SiO_2 surface because the electrodes do not cover the whole surface. Temperature drift is a serious problem in an electric field sensor because the electrodes are usually unterminated and the sensor elements integrate charges in a surrounding. One way to improve the temperature drift is shown in Fig. 4 (b). A Si semiconducting coat is inserted between the electrode and the SiO_2 layer to make the charge uniformity and to discharge accumulated charge on the electrode.

Characteristics

The optical bias angle and the temperature drift of the sensor were measured to confirm the sensor performance. The optical output against the applied voltage is shown in Fig. 5. A 10[kHz] triangular wave was applied directly to the electrode of the sensor. The optical bias angle can be obtained from the maximum and minimum output levels and the level when the applied voltage is zero. When no stress is applied to the $LiNbO_3$, the angle is about 40[$deg.$]. The bias angle can be tuned to 90[deg] by applying a suitable stress, as shown in Fig. 5.

The relationship between the optical bias angle and sensitivity is shown in Fig. 6. When a suitable stress is applied to $LiNbO_3$ substrate by the screw, the optical bias angle and sensitivity are changed. This figure shows that when the optical bias is tuned to about 90[$deg.$], the sensitivity of the sensor is improved by about 6[dB].

The temperature drift of the sensor is shown in Figs. 7(a) and (b). Since the temperature drift of the sensitivity is closely related to the drift in opti-

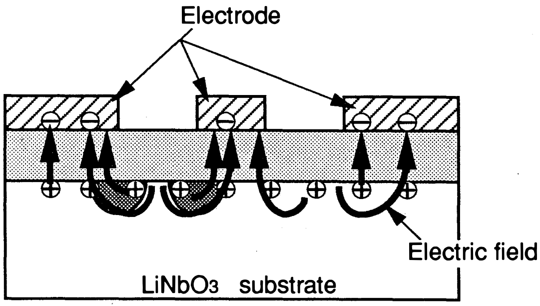

Fig. 4(a) Mechanisms of the temperature drift.

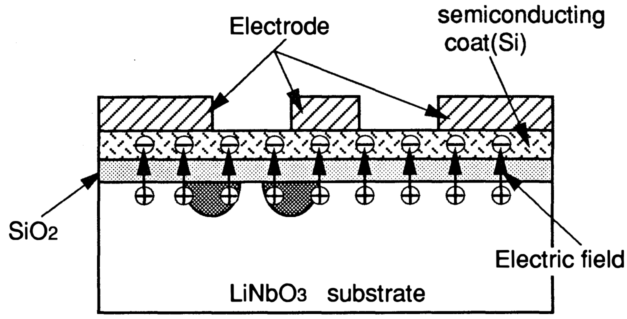

Fig. 4(b) Solution preventing the temperature drift.

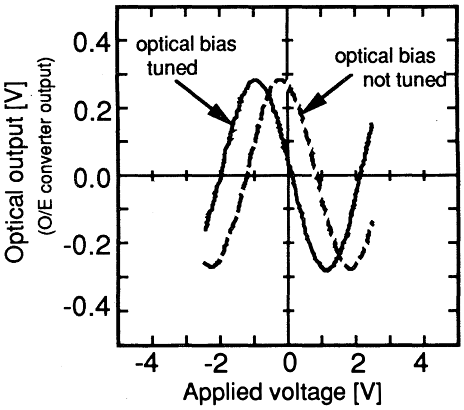

Fig.5 Measurement results of relation between optical output level and applied voltage

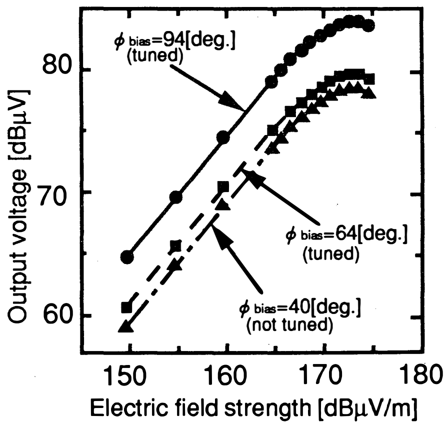

Fig. 6 Measurement results of relation between the optical bias angle and sensitivity

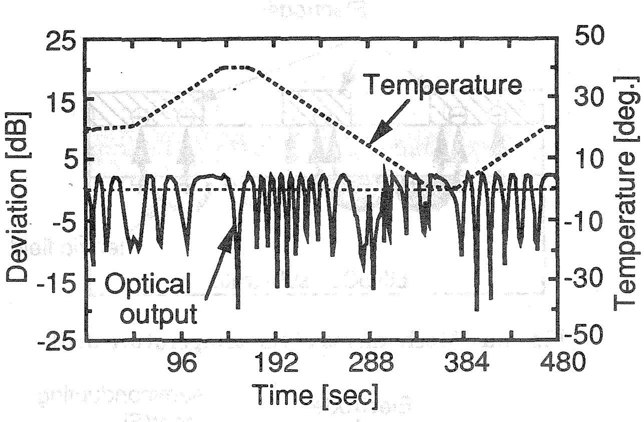

Fig. 7(a) Optical output power deviation of the electric field sensor without Si coat

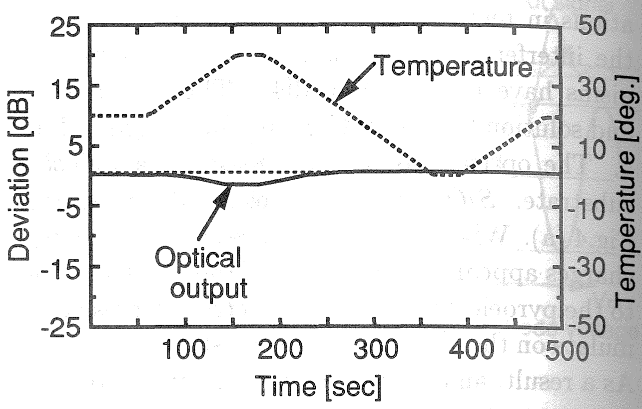

Fig. 7(b) Optical output power deviation of the electric field sensor with Si coat

cal power output, the temperature dependence of the optical output power is measured. The sensor was installed in a chamber where the temperature was changed over the range from 0 to 40[*deg.*] during a 500 minute cycle. The optical power output of the sensor was measured using an optical power meter.

Figure 7(a) shows the temperature dependence of the output optical power when the interferometer was not coated with a Si semiconductor. In this figure, the deviation is about 25[*dB*] from 0[*deg.*] to 40[*deg.*].

Figure 7(b) shows the temperature stabilization provided by effect of Si coat on the sensor. The optical power deviation is less than 2[*dB*] from 0[*deg.*] to 40[*deg.*].

Conclusions

An electric field sensor with a tunable optical bias angle and low temperature drift has been developed. The optical bias angle could be tuned from 40[*deg.*] to 90[*deg.*] by applying a suitable stress to the $LiNbO_3$ substrate. The sensitivity was improved by about 6[*dB*].

The temperature drift was improved by inserting Si semiconductor layer between the electrode and SiO_2 buffer layer. The temperature drift was less than 2[*dB*] over the temperature range of 0 to 40[*deg.*].

Acknowledgment

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